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E-beam irradiation effect on CdSe/ZnSe QDs formation by MBE

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Abstract. The strong influence of the RHEED e-beam irradiation on formation of CdSe QDs by MBE has been found. Large difference in CL spectra between inside the e-beam trace and outside it was observed. Probably, the e-beam stimulates the adatoms diffusion along the growth surface and/or plays role of a catalyst of chemical reaction between Cd and Se.

1. Introduction

Self-assembling quantum dot structures (QDs) are promising active medium for semiconductor lasers [1], in particular for e-beam longitudinally pumped lasers [2]. CdSe/ZnSe system is interesting for visual spectral range. Process of self-assembled QD layers depends strongly on growth procedure, temperature, layer thickness and other growth conditions [3–7]. So *in-situ* control of QD formation is very important. The reflective high-energy electron diffraction (RHEED) is usually used as a control during molecular beam epitaxy (MBE). At the formation of zero-dimensional entities, the RHEED pattern undergoes typically a sharp transition from streaky to spotty [8]. However, only small area of a wafer is monitored in such a way. We have observed that the other area of the wafer has very different emission spectrum. It proves that RHEED e-beam has an influence on the QD formation during MBE.

2. Experiment

Studied structures were grown on GaAs(100) by MBE and contained single or 15 CdSe layers separated by ZnSe barriers. The thickness of each CdSe layer was in 3–5 monolayer (ML) range. In the multiple CdSe/ZnSe layer structures the thickness of ZnSe was 50 or 200 nm. This was large enough to reject any influence of the CdSe layers on each other. Such a design was taken for future investigation of stimulated emission under e-beam pumping.

Growth of the ZnSe buffer was carried out at $T = 280$°C and a VI/II flux ratio of 3:1. The CdSe layer was deposited at smaller temperature $T = 230$°C. After deposition of each CdSe layer, the Cd beam was blocked and the structure was heated up to $T = 340$°C and then cooled to $T = 280$°C under Se flux. Time duration of temperature increase and decrease was 4 and 5 minutes respectively. After such procedure, next ZnSe barrier or top layer was grown. The RHEED e-beam was switched on before the CdSe deposition and switched off before the following ZnSe growth. Its parameters were the following: 0.2 mA current, 12 keV electron energy, 0.5 mm e-beam diameter near the growth surface and 3° angle between the e-beam and the growth surface.

3. Results and discussion

Typical changes of the RHEED patterns during the CdSe deposition followed by the heating procedure were presented in Fig. 1. Before the CdSe deposition (Fig.1a) the RHEED pattern was streaky. This proves that the ZnSe surface was flat enough. During the CdSe

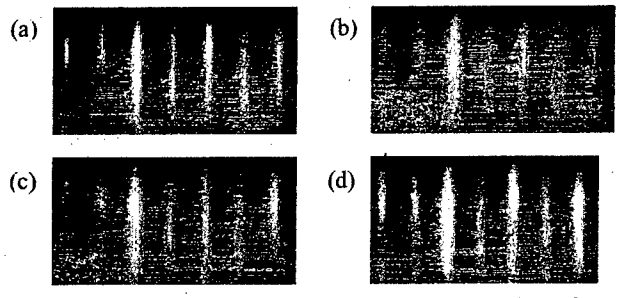

Fig. 1. The RHEED patterns at different time moments of the growth: before (a) and after (b) 3 ML CdSe deposition at $T = 230°C$, and after heating to 340°C (c) and after cooling to $T = 230°C$ (d) under Se flux.

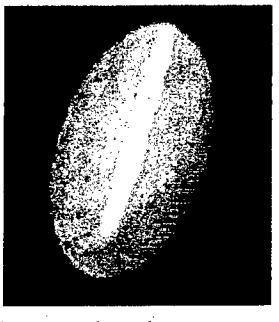

Fig. 2. CL image of the RHEED e-beam track on the structure with 15 CdSe layers and 50 nm thick ZnSe barriers. Oval spot is an area excited by CL e-beam of 5 mm in diameter. The white stripe inside the spot emits in yellow spectral range while the other part of the spot emits in blue-green spectral range.

deposition (Fig. 1(b)) the reflex width increased and a contrast of the diffraction reflexes became smaller. However, there weren't any features of 3-dimensional growth at this stage. The spotty pattern appeared more clearly only at a cooling stage (Fig. 1(d)).

Cathodoluminescence (CL) measurements at electron energy of 10–30 keV, current density up to 1 mA/cm^2, e-beam diameter from 10 to 0.1 mm and $T = 300$ and 14 K were carried out. The CL image of a small area of the structure with 15 CdSe layers and 50 nm thick ZnSe barriers is shown in Fig. 2 at room temperature. Oval spot on the image is the area excited by the e-beam of 5 mm in diameter. The e-beam drops on the sample surface at 45° angle. Most of the spot area emits in green-blue spectral range while an 0.5 mm thick stripe inside the spot emits in yellow spectral range (lighter stripe). It should be noted that total intensity of the stripe emission was higher (about 2.5 times for this structure) than that from the other area. This stripe is the RHEED e-beam track. Such a difference may be due to strong influence of the RHEED e-beam on the CdSe QDs formation.

In Fig. 3 the comparison of CL spectra of the RHEED e-beam trace and outside the trace is shown for different structures at RT. The CL spectrum of the structure with one CdSe layer outside the RHEED e-beam trace contains a wide emission band with maximum at 610 nm. This band is probably caused by deep level defects. Besides, there are two lines with maximum at 461 and 478 nm (Fig. 3(a)). The first is an emission line due to the ZnSe buffer layer and the second may be an emission of thin wet CdSe (or ZnCdSe) layer. The CL spectrum of the RHEED e-beam trace contains an intense line with maximum at 518 nm instead of the 478 nm line and more weak emission from the ZnSe barrier and deep levels

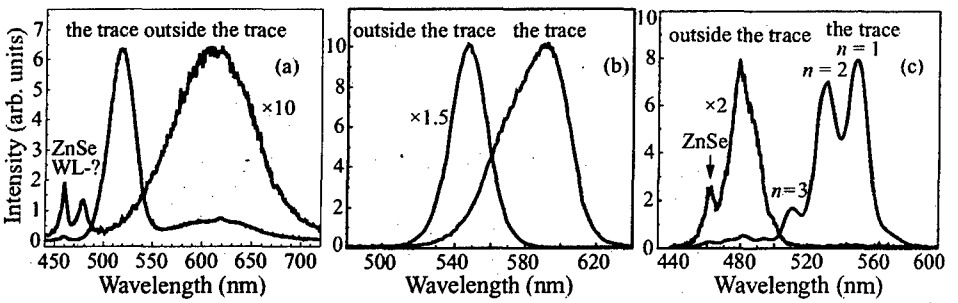

Fig. 3. Comparison of CL spectra from the RHEED e-beam track and an area outside the trace for three different structures contained 1 CdSe layer (a) or 15 CdSe layers separated by 50 nm (b) and 200 nm (c) thick ZnSe barriers, at RT, 1 mA/cm^2 current density and 10 keV electron energy.

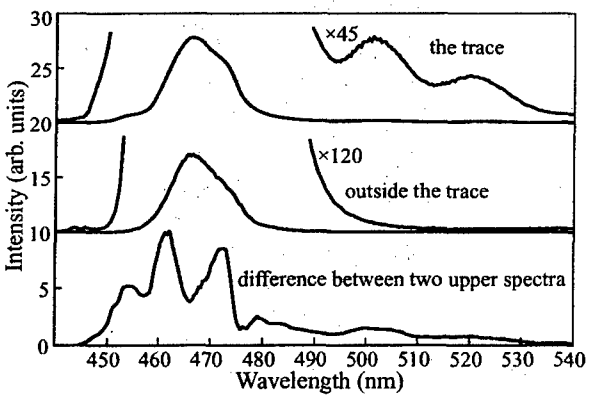

Fig. 4. The 14 K temperature CL spectra of the structure with 15 CdSe layers and 200 nm ZnSe barriers from the RHEEDe-beam trace (upper spectra) and outside the trace (middle spectra) and difference of these spectra (lower spectrum).

defects. In this case the e-beam irradiation essentially improves efficiency of CdSe related emission. The structures with 15 CdSe layers (Fig. 3(a), 3(b)) show more intense CdSe related emission even outside the RHEED e-beam track. Nevertheless the total intensity of the emission from the trace is higher again. Besides, the wavelength maximum of the CdSe related emission shifts to long-wavelength side from 547 nm to 590 nm and from 480 nm to 549 nm for the structure with 50 nm (Fig. 3(b)) and 200 nm (Fig. 3(c)) thick ZnSe barrier layers respectively. Moreover for last structure the CdSe related emission spectrum from the trace consists of several lines with maximum at 549, 531 and 510 nm. At 10 keV excitation only one CdSe layer of this structure is in the excitation area. Indeed the electron penetration depth is 250 nm at 10 keV but the total thickness of the 100 nm thick ZnSe top layer and the 200 nm ZnSe barrier layer separating the first CdSe layer from the next is 300 nm. It means that the different lines are not due to different CdSe layers. However, even at 30 keV (the penetration depth is about 2.3 μm), CL spectrum is practically the same. Such a spectrum is very close to the one observed for InAs/GaAs QDs [9, 10]. By analogy with InAs QDs we suppose that the observed spectrum is related to emission from not only ground level in QDs (line with 549 nm maximum) but also from excited levels $n = 2$ and 3 (lines with $\lambda_{max} = 531$ and 510 nm). Then the full width at haft maximum (FWHM) of the lines is small enough and equal to 66 meV. In Fig. 4, similar CL spectra for the 15 CdSe layer structure with 200 nm ZnSe barriers are presented

at $T = 14$ K. At low temperature the CL spectra from the track and outside it are more close than at RT. Nevertheless some differences in the form of spectral lines especially on the low-wavelength tail are observed. For clearness, a calculated spectrum difference is presented in Fig. 4 by the lower curve. There are several lines on this spectrum. The lines with $\lambda_{max} = 481$, 501 and 520 nm are likely to correspond to the lines with $\lambda_{max} = 510$, 531 and 549 nm at RT (Fig. 3(c)). The other lines with $\lambda_{max} = 454$, 462 and 472 nm may also have some analogues in the 465–500 nm spectral range at RT. However, it is difficult to do such a comparison because of other intense line with $\lambda_{max} = 465$ nm in this spectral range. To explain the observed spectral features we suppose that the CdSe layer outside the RHEED e-beam trace constitutes the layer with nonuniform thickness. This nonuniformity leads to very strong localization of excitons at low temperature. This localization should not be presented as formation of QDs with regular form. However, such formation is likely to occur under the e-beam irradiation. In this case some CdSe material stays in the layer form. Such CdSe layer is likely to be responsible for intense emission line with $\lambda_{max} = 465$ nm at $T = 14$ K. At low temperature the transport of excitons to the CdSe QDs is difficult because of the strong localization in the CdSe-related layer. At RT the transport is easier and the CdSe QD emission becomes predominant in the spectrum.

Mechanism of the e-beam influence on CdSe QDs formation is not clear yet. Probably, the e-beam stimulates the adatoms diffusion along the growth surface and/or plays role of a catalyst of chemical reaction. However, it is clear that rejection of such an effect may lead to mistake in interpretation of RHEED and optical measurements carried out on samples cut from different parts of a structure. On the other hand the observed effect may be used for purposeful improvement of QD formation procedure.

4. Conclusion

In conclusion the strong influence of the RHEED e-beam irradiation on CdSe QDs formation has been found. Large difference in CL spectra from the e-beam track and outside the track was observed. The emission spectrum of the CdSe QDs formed under e-beam has a set of lines due to excited levels in the QDs.

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References

[1] Zh. I. Alferov, *Semiconductors* **32**, 3 (1998).
[2] N. G. Basov, E. M. Dianov, V. I. Kozlovsky, A. B. Krysa, A. S. Nasibov, Yu. M. Popov, A. M. Prokhorov, P. A. Trubenko and E. A. Shcherbakov, *Laser Physics* **6**, 608 (1996).
[3] K. Leonardi, H. Heinke, K. Ohkawa, D. Hommel, H. Selke, F. Gindele and U. Woggon, *Appl. Phys. Lett.* **71**, 1510 (1997).
[4] H. Kirmse, R. Schneider, M. Rabe, W. Neumann and F. Henneberger, *Appl. Phys. Lett.* **72**, 1329 (1998).
[5] C. S. Kim, M. Kim, S. Lee, J. K. Furdyna, M. Dobrowolska, H. Rho, L. M. Smith, H. E. Jackson and J. L. Merz, *J. Cryst. Growth* **214/215**, 761 (2000).
[6] S. V. Ivanov, A. A. Toropov, T. V. Shubina, S. V. Sorokin, A. V. Lebedev, I. V. Sedova, P. S. Kop'ev, G. R. Pozina, J. P. Bergman and B. Monemar, *J. Appl. Phys.* **83**, 3168 (1998).
[7] P. A. Trubenko, V. I. Kozlovsky and V. V. Roddatis, *J. Cryst. Growth* **214/215**, 671 (2000).
[8] K. Arai, T. Hanada and T. Yao, *J. Cryst. Growth* **214/215**, 703 (2000).
[9] J. J. Dudowski, C. Ni Allen and S. Fafard, *Appl. Phys. Lett.* **77**, 3583 (2000).
[10] Z. R. Wasilewski, S. Fafard and J. P. McCaffrey, *J. Cryst. Growth* **201/202**, 1131 (1999).